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Color Vision Changes and Effects of High Contrast Visor Use at Simulated Cabin Altitudes

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14. ABSTRACT

Color vision is sensitive to hypoxia and may degrade with altitude exposure. These effects may be clinically and operationally significant, especially for aircrew utilizing color multi-function displays. High-contrast visor (HCV) use may exaggerate these changes, as its use is known to distort color perception. The purpose of this research was to evaluate the effects of simulated altitude exposure on color vision and whether using the HCV would result in further degradation of color vision under these conditions. Following Institutional Review Board approval, a reduced oxygen breathing device was used to expose subjects with normal color vision to simulated cabin altitudes of ground level, 12,000 feet, and 8,000 feet. A computerized cone contrast test was used to assess color vision with, and without, the HCV at each simulated altitude. Utilizing 12 subjects, the results showed it was possible to demonstrate decreases in color vision between ground level and a simulated altitude in the absence of HCV use. The association depended on which cone [S (blue), M (green), or L (red)] was evaluated, with the S cone showing the greatest decrease at 8,000 feet. High-contrast visor use at simulated altitudes did not demonstrate a significant decrease in color vision. This study examined the feasibility of combining normobaric hypoxia exposure, advanced color vision screening techniques, and HCV use for the study of color vision in aviators. Our results suggest normobaric hypoxia exposure and computerized color vision testing may be a safe and useful modality for studying the effects of altitude on vision.

15. SUBJECT TERMS

Normobaric, hypoxia, altitude, color vision, high contrast visor, reduced oxygen breathing device

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1.0 SUMMARY

Color vision is sensitive to hypoxia and may degrade with altitude exposure. These effects may be clinically and operationally significant, especially for aircrew utilizing color multi-function displays. High-contrast visor (HCV) use may exaggerate these changes, as its use is known to distort color perception. The purpose of this research was to evaluate the effects of simulated altitude exposure on color vision and whether using the HCV would result in further degradation of color vision under these conditions. Following Institutional Review Board approval, a reduced oxygen breathing device was used to expose subjects with normal color vision to simulated cabin altitudes of ground level, 12,000 feet, and 8,000 feet. A computerized cone contrast test was used to assess color vision with, and without, the HCV at each simulated altitude. Utilizing 12 subjects, the results showed it was possible to demonstrate decreases in color vision between ground level and a simulated altitude in the absence of HCV use. The association depended on which cone [S (blue), M (green), or L (red)] was evaluated, with the S cone showing the greatest decrease at 8,000 feet. High-contrast visor use at simulated altitudes did not demonstrate a significant decrease in color vision. This study examined the feasibility of combining normobaric hypoxia exposure, advanced color vision screening techniques, and HCV use for the study of color vision in aviators. Our results suggest normobaric hypoxia exposure and computerized color vision testing may be a safe and useful modality for studying the effects of altitude on vision.

2.0 INTRODUCTION

Color vision has long been considered an important attribute for the military aviator. Modern cockpits utilize a myriad of color displays to convey information such as aircraft status, warning signals, surrounding aircraft, and terrain. Therefore, degraded color perception in the cockpit has increasingly become a concern for military operations. Color vision is especially sensitive to hypoxia and may deteriorate with increased altitudes, especially above 10,000 feet [1,2]. It is also known that the color perceiving cone cells in the central portion of the retina are responsive to tissue hypoxia that occurs at relatively low altitudes [1,3-5]. Color vision changes have previously been reported at altitudes as low as 8,000 feet, an altitude commonly experienced by aircrew even in a pressurized aircraft cabin [6]. Surprisingly, after over 100 years of research, there are still inconsistent study results as to the precise nature and degree of color vision loss at altitude [5]. This can be due to a variety of differences in comparisons, experimental techniques, and samples sizes, among other factors. Unfortunately, there is limited modern research addressing the effects on color vision experienced by individuals in the altitude environment representing common cabin altitude levels between 8,000 and 12,500 feet. There have been even fewer studies utilizing modern color vision testing techniques, such as those used by the U.S. Air Force (USAF) in aviator medical selection and research, at these critical altitudes.

The Federal Aviation Administration requires aircrew to use supplemental oxygen when operating at cabin altitudes above 12,500 feet for greater than 30 minutes, but does not require passengers to be provided supplemental oxygen until 15,000 feet [7]. The Federal Aviation Administration also mandates that pressurized aircraft cabins not exceed 8,000 feet pressure altitude under normal operating conditions [8]. Current USAF regulations allow aviators to operate for a maximum of 30 minutes between cabin altitudes of 12,500 feet and 14,000 feet

without supplemental oxygen. Aircrew may operate without supplemental oxygen for unlimited periods between cabin altitudes of 10,000 feet through 12,500 feet unless they are performing certain operational duties, including night flying, instrument meteorological conditions flying, air drop operations, aerial refueling, high-g flying, and weapons employment [9]. While performing these duties, aircrew must be on supplemental oxygen if they remain between 10,000 and 12,500 feet for greater than 60 minutes [9].

Altitude training and research can now be performed utilizing advanced systems that safely simulate altitude exposure and the resulting hypoxia. The reduced oxygen breathing device (ROBD) is a physiologic system now commonly used to train U.S. military aviators. It works by altering the fraction of nitrogen in the inspired air to create a hypoxic environment similar to that experienced at altitude [10]. This is termed normobaric hypoxia [11]. The benefits of the ROBD are that it can simulate altitude exposure and allow hypoxia research without exposing the individual (or the trainer) to the additional risks of barotrauma and decompression sickness associated with the hypobaric altitude chamber training environment [11]. Additional benefits of ROBD use in aerospace medicine research include the device’s small physical dimensions and low operating and manufacturing costs [11].

The high-contrast visor (HCV) is a yellow-tinted visor used by pilots to enhance their vision outside the aircraft in degraded visual environments, such as hazy weather [12]. It is hypothesized these act to increase contrast by blocking short wavelength colors from entering the eye, thus increasing the contrast of non-blue objects when seen against a blue background (such as sky or water) [12]. The operational effect of this would be to potentially make enemy aircraft easier to spot for pilots. However, by blocking the visible spectrum in a non-neutral manner, the HCV is known to affect color vision and distort color perception [12]. It is postulated that these visors could reduce color abnormals to a completely color blind state [12]; thus, their use in the USAF is limited only to those with normal color vision. It also raises the question of whether the additive combination of altitude-induced hypoxia and HCV use could result in operationally significant color vision deficits, even in color normal individuals.

Historical tests of color vision and hypoxia were limited in the manner in which color vision could be assessed. Methods such as pseudoisochromatic plate testing are relatively insensitive, whereas tests such as the FM100 may offer more sensitivity, but have a greater cost in logistics and administration time. Over the last few years, the USAF School of Aerospace Medicine (USAFSAM) staff have helped develop a variety of computer-based color vision screening tools, including the cone contrast test (CCT). These automated color vision testing techniques significantly improve the sensitivity and reliability of aircrew color vision screening compared to older methods and are effective for determining the presence, type, and severity of color vision deficiencies [13]. USAFSAM researchers have recently implemented an additional upgrade to the CCT software and hardware, further increasing the sensitivity and specificity of the screening. In addition, a new user interface for this enhanced CCT allows the test to be rapidly administered in a manner that is simpler and faster for subjects to complete.

Despite these advances, a study of color vision at altitude has not been previously performed using this enhanced CCT. For this study we proposed using the ROBD to expose subjects to simulated altitudes, allowing researchers to rapidly assess the subjects’ color vision and the effects of the HCV utilizing the enhanced CCT under mildly hypoxic conditions. Simulated altitudes were selected to represent the maximum levels allowed for aircraft pressurization and flight without supplemental oxygen that might be commonly encountered by military and civilian aviators. The overall purpose of this research was to evaluate the effects of

common aircraft cabin altitudes on color vision and whether using an HCV at altitude would result in further degradation of color vision. Additionally, it was postulated the study would allow researchers to build the foundation for subsequent studies utilizing normobaric and hypobaric environments while performing color vision testing and research.

3.0 METHODS

The study protocol was approved in advance by the Air Force Research Laboratory Institutional Review Board. All research trials were conducted at USAFSAM, Wright-Patterson Air Force Base, OH.

3.1 Subjects

A total of 12 human subjects participated in this study, 9 men and 3 women (mean 35.8 years old, range 20-47 years old). All subjects were non-smokers, with normal color vision. Subjects were volunteers from USAFSAM and Wright-Patterson Air Force Base who had previously received altitude chamber training. All subjects were on active flight status or had previously been medically cleared for altitude exposure and training. All enrolled subjects completed the study protocol.

3.2 Equipment

The research utilized the Environics ROBD2 machine (Environics Inc., Tolland, CT) to simulate altitude. The ROBD2 uses flow controllers to mix breathing air and nitrogen to produce an equivalent atmospheric composition for the simulated altitudes. The machine was operated by a trained USAF aerospace physiologist or aerospace physiology support technician for all trials. Continuous pulse oximetry was monitored for safety through the ROBD2 utilizing the built-in sensor, which was placed on the subject's index finger. The ROBD2 device used in this training setting is constructed so subjects "fly" a single-seat fighter aircraft simulator while connected to the device. Color vision testing was performed using a second-generation enhanced research CCT developed by scientists from USAFSAM's Operational Based Vision Assessment team. The CCT program was loaded onto a standard desktop computer, with the test displayed on a high-resolution monitor. The monitor was situated next to the simulator screen and adjusted to a viewing distance of 30 inches from the subject. Color images were presented to subjects in the form of a Landolt C. Data for each subject trial were collected in the desktop computer and stored for further statistical analysis.

3.3 Procedures

All subjects reviewed and signed a standardized informed consent document prior to participation. Current medical qualifications and altitude chamber training history were also verified on the day of study participation. Subjects were allowed to wear their normal eyeglasses or contact lenses. Each underwent vision screening by an optometry technician to verify 20/20 vision, using a wall-mounted chart for distant vision and a hand-held screening card for near vision. Subjects were not allowed to use bifocal lenses during the study. A life support specialist then fit a standard USAF aviator mask and helmet. The HCV was mounted to the

helmet, ready to be lowered for use. Next, subjects had their color vision tested under binocular conditions using the research CCT. All color vision testing for the study was performed under binocular conditions in a darkened room. During every phase of the testing, each of the three retinal cones, S (blue), L (red), and M (green), was tested. This was done first without, then with, the HCV. Initial testing, prior to altitude exposure, was performed at ground level. The actual altitude at this location was approximately 850 feet above sea level. The subjects were then taken to 12,000 feet simulated altitude for 30 minutes and their color vision was again tested without, then with, the HCV. The subjects were then taken to 8,000 feet simulated altitude, with a 5-minute delay at this new altitude to allow the subjects to acclimatize, and color vision was tested without, and then with, the HCV. Finally, the subjects were returned to ground level and allowed to breathe normal room air. After clearance from the ROBD operator, their study participation was concluded. The maximum simulated altitude for the trial was 12,000 feet and total exposure to the normobaric gas mixture was 60-70 minutes.

3.4 Statistical Analysis

The experimental data were initially archived in Microsoft Access and then transferred to SAS and Microsoft Excel for statistical analysis. Data were log transformed due to the large differences in scale among the contrast sensitivity ranges of the individual cones. The data were analyzed using a repeated measures analysis with three fixed-effects (altitude, cone, visor). There were 18 one-sided comparisons of interest identified a priori, and a Bonferroni adjustment for multiple comparisons was used (Table 1). Therefore, a *p*-value for an individual test of less than 0.0028 was considered statistically significant to preserve the family-wise error rate of 5% ($\alpha = 0.05$).

Table 1. Test of Fixed Effects between Variables

Effect	Numerator DF	Denominator DF	F Value	Pr > F
Altitude	2	22	1.56	0.2316
Visor	1	11	0.00	0.9765
Visor*Altitude	2	22	0.04	0.9572
Cone	2	22	2611.76	<0.0001
Cone*Altitude	4	44	1.49	0.2213
Cone*Visor	2	22	4.11	0.0303
Cone*Visor*Altitude	4	44	2.65	0.0457

DF = degrees of freedom.

4.0 RESULTS

4.1 Color Vision Testing without High-Contrast Visor

A significant decrease in color contrast sensitivity was noted in the S (blue) cone between ground level and 8,000 feet simulated altitude (p=0.0009) (Figure 1). There were no significant decreases in color contrast sensitivity noted in the L (red) or M (green) cones at any simulated altitudes.

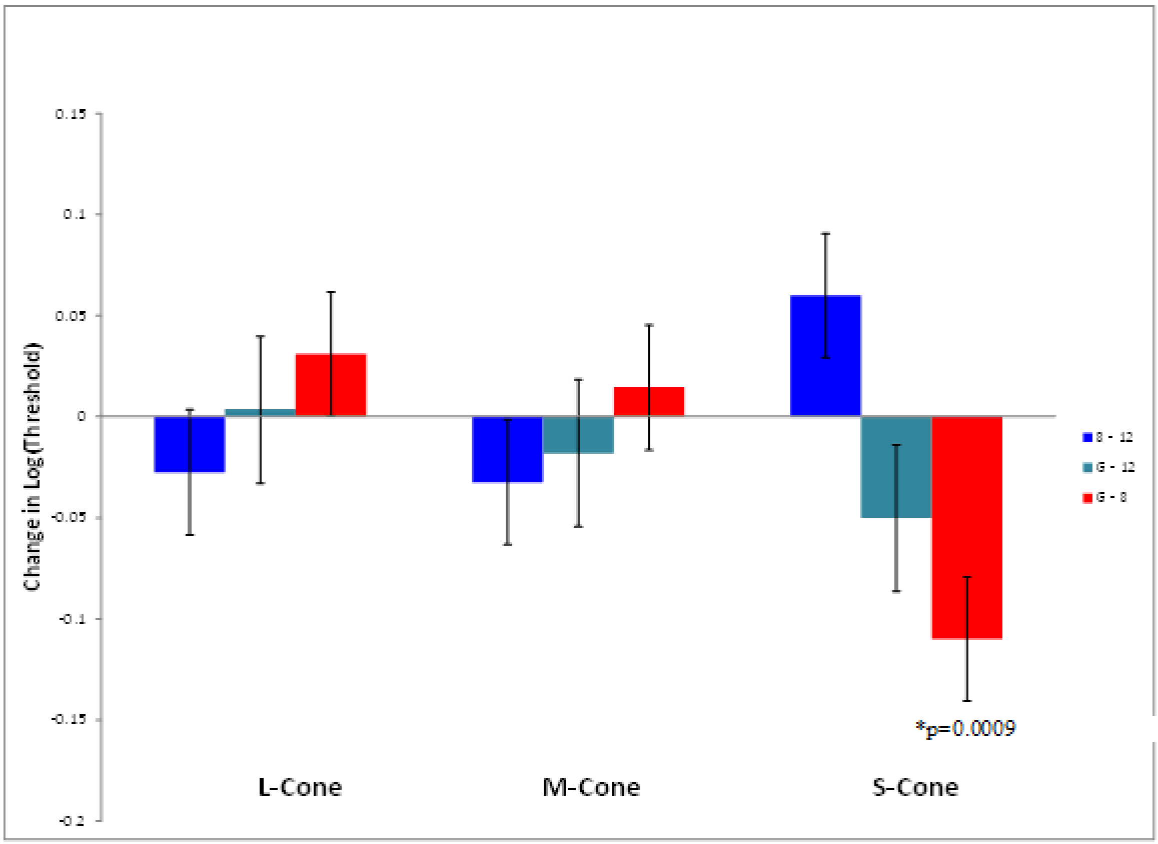

Figure 1. Mean changes in log (threshold) with altitude, by cone (without HCV).

4.2 Color Vision Testing with High-Contrast Visor

The addition of the HCV did not demonstrate a significant decrease in contrast sensitivity at any of the simulated altitudes when using this particular color vision screening technique (Figure 2). We feel this finding should be interpreted cautiously based on the experimental setup and not taken as evidence that HCV has no effect on color vision at altitude. This will be discussed further in the following sections.

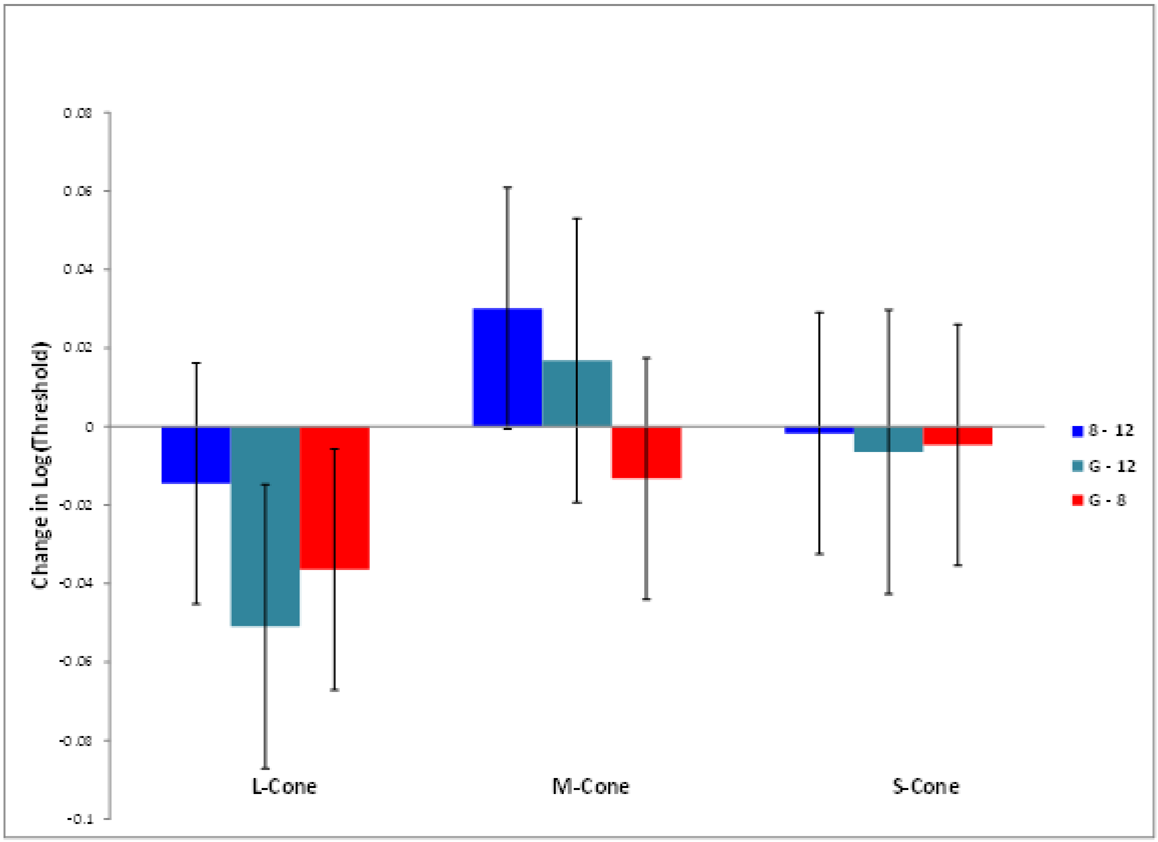

Figure 2. Mean changes in log (threshold) with altitude, by cone (with HCV).

In the absence of the HCV, the results revealed a significant decrease in the contrast sensitivity noted in the S cone between ground level and 8,000 feet simulated altitude when using the enhanced CCT. This is possibly explained due to the S cones reportedly being less numerous (representing only 5-10% of the total cones), with the other cones distributed evenly between M and L [14]. Additionally, the S cone is thought to be more sensitive to hypoxia [14], with reports suggesting the M cone may actually receive a greater blood supply [15]. Previous literature suggests the altitude-induced hypoxia may predominantly affect color vision in the tritan (blue) axis [5,16], a finding this study may also support. While our study results in the S cone were significant, it should be noted this is a small study with low subject numbers, low power, and a single outlying data point in the 8,000-foot range that appeared to influence the overall results at this altitude.

The addition of the HCV did not demonstrate a significant decrease in contrast sensitivity at any of the simulated altitudes. In this study the lack of changes in color vision while using the HCV was thought to be a limitation of the enhanced CCT itself and should not be considered evidence that HCV use at altitude has no demonstrable degradation on color vision. Specifically, the CCT works by presenting a color stimulus with specific color coordinates against a monochromatic background, again with a very specific color coordinate. Under normal viewing conditions, this is an effective method to identify color anomalies. But with HCV use, the color coordinates of the stimulus and background are modified such that individual cones are no longer isolated. That, coupled with the fact that the CCT does not control for luminance cues, allowed

the HCV user to effectively "see" the stimulus based on shading cues and not color. A more effective computerized test to evaluate color vision while using the HCV would have been to present the stimulus against a multi-colored background. This would have worked to effectively "hide" the stimulus further and eliminate luminance cues. Recall that older USAF legacy color vision testing utilized a similar method of presenting colored numbers against a multi-colored background with pseudoisochromatic plate testing. This revelation was not foreseen and, although this might be considered a negative study result, it still adds considerably to the general knowledge base on the use of the CCT in the evaluation of color vision and the HCV. Recently developed computerized automated color vision testing modalities can now perform this type of task, but were not readily available to the research team at the time of this study and required more time than could have been practically accommodated while subjects were connected to the ROBD device.

Additional limitations of this preliminary study worthy of discussion would include the small sample size (n=12) and the fact that all subjects had normal color vision and were exposed only to a relatively brief, mild hypoxia. The low sample size does suggest the study results are of low power and further study may be recommended for validation. It would have been potentially valuable to have a larger subject pool with both color normal and abnormals involved. This may have revealed differential drops in color perception based on reference color vision readings for each subject. As this study only looked at simulated altitudes of 12,000 feet and 8,000 feet, the relative hypoxia experienced by subjects was only mild and for a short duration. Pulse oximetry levels were monitored for safety, but were not formally recorded for subjects during this study. Researcher team monitoring of pulse oximetry did confirm hypoxia in the subjects, with oxygen saturation values commonly noted in the low to mid 80% range at the simulated altitudes. Future studies should include recorded observation of maximum decrease in oxygen saturation values for each subject at each simulated altitude to further quantify this variable.

6.0 CONCLUSIONS

The results of this study suggest normobaric hypoxia and computerized color vision testing may be useful for studying the effects of altitude on color vision. Compared with hypobaric altitude chamber exposure, this method has an enhanced safety profile, decreased cost, and fewer complex logistic challenges. Because this research successfully identified a gap in our knowledge of how to study HCV use with advanced computerized color vision testing techniques, it may provide the groundwork for future research utilizing automated color vision testing, normobaric hypoxia, and HCV use. The results of studies such as this could have meaningful impact on future aviator selection, aircrew equipment requirements, and aviation mishap prevention programs.

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LIST OF ABBREVIATIONS AND ACRONYMS

CCT	cone contrast test
HCV	high-contrast visor
ROBD	reduced oxygen breathing device
USAF	U.S. Air Force
USAFSAM	U.S. Air Force School of Aerospace Medicine